SYSTEM IDENTIFICATION AND PID CONTROL OF TOOTHBRUSH SIMULATOR SYSTEM

AINUL HUSNA BINTI MOHD YUSOFF

A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

MARCH, 2019

DEDICATION

This research project is dedicated specially to my beloved parents Mohd Yusoff Bin Harun and Kamaliah Binti Kamisan for their tremendous support, love, encouragement and prays of day and night. Not forgetting my beloved siblings Ainul Hanani, Ainul Huda and Ahmad Yusri, thank you for the continuous inspiration. Also, to all my friends, thanks for the encouragement. Thank you for all the prays that make me able to finish up this research project. Along with hard working and respected supervisor, co-supervisor, and lecturers.

ACKNOWLEDGEMENT

I would like to acknowledge every person that has supported me throughout my master's degree. I would like to give sincere thanks to my supervisor, Assoc. Prof. Ts. Dr. Salihatun Binti Md Salleh for her constant guidance as well as providing necessary information and requirement needed throughout this research project. Thank you for her tremendous support and inspiration that makes me able to finish up this research project. Furthermore, thank you to have a believed in me to carry out this project. I am feeling grateful to have her as my research advisor.

Also, thank you to my co-supervisor, Dr. Nadia Binti Halib in providing important information related to this project and her continuous support that makes me feel determined to do this research project. Thank you for believing in me to conduct this research project. I would like to thank my family members and close friends for continuous encouragement. You have all believed in me which helped me to keep focus and determine to finish this research project.

ABSTRACT

Toothbrush simulator was invented for industry and dentist researchers to do research related to plaque removal. The toothbrush simulator system repeatedly has a problem in achieving the desired speed control. The brushing movement is inconsistence and stops eventually if there is a force exerted on the toothbrush holder. Further research is required to increase the reliability and controllability of the speed response achievable from the toothbrush simulator system. In this study, a PID controller is designed and embedded in the system. A real-time experiment has been conducted on the real system via the Matlab Simulink environment to construct the model. The model parameters are optimized with model order 2, 3 and 4 where each model order has been analyzed for ten (10) times iteration by the genetic algorithm in obtaining the accurate transfer function. The model has been validated through correlation analysis. The PID controller was tuned through the PID tuner and Ziegler-Nichols method. Simulated and real-time system response from both tuning methods was compared. The simulated response with the selected PID controller is then compared with the response from the real-time experiment. The closed-loop system without controller was compared with the response with the PID controller. The PID controller was then deployed into the real system by uploaded into the microcontroller. The brushing simulator remote control was created to control the desired speed through a smartphone. Genetic algorithm model based on model order 4 has been selected as the best model as it able to achieve the minimum MSE value of 0.0176 and past all the validation tests. The selected PID parameters was from PID tuner tuning method with gain values of; Kp= 17.9287, Ki= 40.751 and Kd= -0.52705. Both results of simulation and real-time tests were compared, and they show about similar performances. The controlled system response had achieved all five desired speed of 175, 195, 215, 235 and 255 rpm with the percentage of improvement 67%, 65%, 65%, 65%, and 68%. Throughout this study, a genetic algorithm model based and tuned PID controller parameters has been applied to the real system improvised in better system response.

ABSTRAK

Simulator berus gigi dicipta untuk penyelidik pergigian membuat kajian berkaitan penyingkiran plak. Pergerakan memberus simulator berus gigi sedia ada tidak sekata, ia menjadi perlahan dan akhirnya berhenti jika tekanan dikenakan ke atas pemegang berus gigi. Kajian selanjutnya diperlukan untuk meningkatkan pengendalian tindak balas kawalan. Dalam kajian ini, pengawal PID direka dan dimasukkan ke dalam sistem. Kajian pada sistem sebenar dijalankan melalui Matlab Simulink untuk membina model. Parameter model telah dioptimumkan dengan tertib 2,3 dan 4 di mana setiap tertib model telah dianalisa sebanyak 10 kali oleh algoritma genetik untuk mendapatkan persamaan yang tepat. Model ini disahkan melalui analisis perkaitan. Pengawal PID dilaraskan melalui pelarasan PID dan kaedah Ziegler-Nichols. Tindak balas simulasi dan sistem sebenar daripada kedua-dua kaedah telah dibandingkan. Tindak balas kelajuan sistem daripada simulasi dan sistem sebenar dengan pengawal PID yang terpilih telah dibandingkan. Tindak balas sistem tertutup tanpa pengawal telah dibandingkan dengan tindak balas pengawal PID. Pengawal PID telah dimasukkan ke dalam sistem sebenar dengan memasukkannya ke dalam mikropengawal. Alat kawalan jauh telah dibuat untuk mengawal kelajuan yang dikehendaki melalui telefon pintar. Model berasaskan algoritm genetik dengan tertib model 4 telah dipilih sebagai model terbaik kerana mampu mencapai nilai minima MSE 0.0176 dan melepasi kesemua ujian pengesahan, Parameter PID yang dipilih adalah daripada kaedah pelarasan PID; K_p= 17.9287, K_i= 40.751 and K_d= -0.52705. Hasil simulasi dan ujian pada sistem sebenar telah dibandingkan, dan keduanya menujukkan prestasi yang lebih kurang sama. Tindak balas system beserta pengawal telah mencapai kelima-lima kelajuan yang dikehendaki 175, 195, 215, 235 dan 255 putaran seminit dengan peratusan peningkatan 67%, 65%, 65%, 65% dan 68%. Melalui kajian ini, model berasaskan algoritma genetik dan parameter pengawal PID yang telah dilaraskan telah diaplikasikan kepada sistem sebenar telah menambah baik tindak balas sistem.

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LIST OF SYMBOLS AND ABBREVIATIONS

PID	Proportional-Integral-Derivative
RCGA	real-coded genetic algorithm
MSE	Mean Square Error
PWM	Pulse Width Modulation
NVAR	number of variations
NIND	number of individuals
MAXGEN	maximum generation
GGAP	generation gap
ACO	Ant Colony Optimization
IR	Infrared
tf	transfer function
$u(t)$	input of the system
y(t)	output of the system
ρ	pheromone decay parameter
Q	quantity of pheromone leaves by ant per iteration
τ_{ij}	amount of the pheromone at that node
$\tau_{\circ}$	constant for the initial value of τ_{ij}
f_{best}	objective function value obtained from the best ant of each searching period
$\varphi_{\varepsilon\varepsilon}(\tau)$	correlated signal of residuals in auto-correlation
$\varphi_{u\varepsilon}(\tau)$	cross-correlation function between input and residuals
K_P	proportional gain
K_I	integral gain
K_D	derivative gain
e_i	error value
N	size of population
y_i	value of actual output data

$\hat{y}_i$	value of predicted output data
l	weight score
j	represents the weight value assigned
k	represents the rating of each criterion
m	total weight score

LIST OF PUBLICATIONS

Journals:

(i) Ainul H.M.Y., Salleh S.M., Halib N., Taib H., Fathi M.S. Analysis of Toothbrush Rig Parameter Estimation Using Different Model Orders in Real-Coded Genetic Algorithm (RCGA). International Journal of Engineering & Technology, 7(4.30), p.443-447. 2018. Scopus Indexed.

(ii) Hakimi, M.H., Salleh, S.M., Ainul, Ngali, M.Z., Ismail, A.E., Rahman, M.N.A., Mahmud, W.M.A.W. Ice Bath Therapy on Athletes Recovery Response Using EEG. International Journal of Engineering & Technology, 7(4.30), p.438-442. 2018. Scopus Indexed.

(iii) Yusof, M.M.M., Salleh, S.M., Ainul, H.M.Y., Siswanto, W.A., Mahmud, W.M.A.W. Analysis of Golfer's Brainwave Signal During Par Tree Ireland and Driving Range Game. International Journal of Engineering & Technology, 7(4.30), p.469-472.2018. Scopus Indexed.

Proceedings:

(i) A.H.M. Yusoff, S. Mahzan, S. Ahmad, H. Taib, H.A. Rahman, A. Ismail, S.M. Salleh. Evaluation of Varies Model Order in GA-optimized Parameter Estimation of Toothbrush Rig System. International Conference on Mechanical Engineering Research and Application (ICOMERA2018), 23-25 October 2018, Malang, Indonesia. Accepted and to be published in International Journal of Integrated Engineering (IJIE). Scopus indexed.

(ii) A.H.M. Yusoff, Salleh S.M., Halib N., Daud N.A. Real-Time Data Acquisition Using Arduino to Develop Real-Coded Genetic Algorithm (RCGA) Based Model. Intelligent, Control and Automation Symposium (ICAS2018), 28 November 2018, UTM Johor Bahru. Conference proceedings.

LIST OF AWARDS

(i) 'PID-Controlled Toothbrush Simulator Using Smartphone-Apps Based Application'. Silver Medal in International Research and Innovation Symposium and Exposition 2018 (RISE2018), 12 & 13 November 2018, Universiti Tun Hussein Onn Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Oral health is vital element in human life as it contributes to the confident level of a person. The most things that closely related with oral health was the dental hygiene. The research on efficiency of plaque removal on tooth is another part that important in oral health. Hence, brushing simulator was invented for dental researcher to do a research on the plaque removal on tooth. Research that is related to the efficiency of tooth cleaning is a continuous research up until now as it is the vital part that contribute to oral health.

A few studies relate with the efficiency of plaque removal such as the type of toothbrush bristle, ingredient of the toothpaste and others. Moreover, Gockel et al., (2001) state that, there are few parameters that affect the efficiency of the teeth cleaning process which is the design of the toothbrush, the bristles arrangement on the toothbrush and the best strategy of teeth cleaning. Hence, the toothbrush simulator offers valuable assistance in oral health research as it provides the motion that resemble the real brushing teeth motion.

Toothbrush simulator involves dual motion which is the rotation motion of the actuator that produce the repetitive back-forth linear motion of the toothbrush holder that controlled by Arduino as a microcontroller. The current toothbrush simulator system operates only at one rate when receiving the speed input signal from potentiometer. However, the toothbrush holder on the toothbrush simulator system was not providing a constant movement as the speed will decreased and stop eventually when there is a force acting on the toothbrush holder.

In this application, the actuator should be precisely controlled to produce the desired performance. This project is mainly concerned about identifying the parametric model of the toothbrush simulator system before the suitable controller parameters can be developed. System identification is used as a method to identify the model of this system which is necessary to collect the input and output data of the toothbrush simulator. A parametric model is a mathematical relationship which describe the input-output relationship from the observed data of the system.

Several speed controllers that can be developed for this system such as proportional-integral-derivative (PID) controller, fuzzy logic controller (FLC) or the combination of both. The PID controller has been chosen to be developed for this system. This was due to the ability of the PID controller in controlling the output signal in a closed-loop system. Moreover, it has been reported most closed-loops system of industrial process control still use this PID controller due to its robust performance in a wide field of operation system, simple to understanding the operators and able to be applied using digital or analog hardware (Zhang et.al, 2004). This statement is supported by Ang et.al, (2007), where PID controller offers the most efficient solution to real world problems in a wide area with the simplest structure.

1.2 Problem Statement

The dental researcher needs a toothbrush simulator to assist their dental research on the relation of brushing speed and type of toothbrush surface on plaque removal efficiency. The toothbrush simulator was important for them as it simulate the brushing teeth motion. This is because by using manual operation, it takes a long time to do adequate tests in achieving the reference stroke values. Hence, the toothbrush simulator was important for dentist researcher in conducting the experiment.

The existing toothbrush simulator does not have any controller to control the system performance. The current system was open-loop system which do not have any controller, it operates on one speed rate with maximum voltage value. The amount of voltage supplied by tuning the potentiometer to the maximum value. The toothbrush simulator system is considered as a dynamic system, where the output response is constantly changing over time.

The disturbance from friction produced between toothbrush holder and the slot surface give a result in the motion of toothbrush holder was not constant as the motion will become slower and stop eventually if there is any force exerted on it. Constant brushing movement important in the dental research as the dental researcher need to achieve the 17,800 strokes which resemble 3 years of brushing teeth motion (de Freitas, 2016). The dental researcher needs that reference strokes value to carry out studies on different testing parameter.

Therefore, the controller approach on the system is recommended to solve this problem. The PID controller will be developed for this toothbrush simulator system. The development of the PID controller is very important due to its ability as a speed controller without being affected by the disturbance such as friction in toothbrush simulator movement. So that, the accurate results of the dental research can be obtained. Then, dental researcher able to come out with a recommendation to toothbrush manufacturer the appropriate toothbrush bristle. As a result, it able to contribute in introducing the optimum brushing method for removal plaque to society.

1.3 Objectives of the Study

There are three objectives that need to be achieved in this project:

(i) To model a voltage-speed parameter of toothbrush simulator system.
(ii) To develop PID controller for toothbrush simulator system.
(iii) To verify the simulation of a controller using MATLAB simulation with experimentation of toothbrush simulator system.

1.4 Scope of Study

This project is focusing on the development of the controller system of toothbrush simulator:

(i) Real-time data extraction for model construction.
(ii) Identifying ARX model of parameter for the system.
(iii) Development of PID controller through PID tuner tuning method and Ziegler-Nichols method.

(iv) Comparison between simulation and real-time testing of system response with tuned PID parameter and Ziegler-Nichols based PID controller.

(v) PID controller verification through MATLAB simulation with real time test by conducting an experiment on a system with the microcontroller-based PID controller.

1.5 Significance of Study

The toothbrush simulator participates in helping the dental researcher to ease the process of toothbrush brushing teeth motion on dental search. Toothbrush simulator with constant brushing motion without being affected by disturbance was needed to do adequate tests because the results from current toothbrush simulator was inconsistence. Therefore, PID controller will be developed on the toothbrush simulator. The developed PID controller will monitor and correct the actual output to follow the desired input automatically.

The development of control system is quite challenging. The Arduino is used as a real-time data acquisition board for the process of developing the model. The application of genetic algorithm helps in estimated the best parameter to get the best model as the requirement for the controller development. Real-coded genetic algorithm (RCGA) is applied for optimization technique rather than binary-coded genetic algorithm (BCGA) because it requires no encoding and decoding process. While, binary coded genetic algorithm (BCGA) may suffer loss of precision during the process of encoding and decoding (Salleh et al., 2009).

A remote-control using smartphone-apps based application is created to activate the system. This make the machine can be operated automatically by receiving the data that has been transferred through the Bluetooth module from the smartphone application. The other usage of Arduino as a microcontroller which will be embedded with PID controller to make it a standalone microcontroller-PID based system. This study has a contribution in development of controller system as the method to develop controller is learned precisely. Through this study, the PID controller can be developed for any system in the future.

1.6 Report Organization

The first chapter is about the introduction about the whole project, objective that need to be achieved and problem statement that lead to this project. Besides, the scope on this project and the significance of the study for the future is included in this chapter. The review from the previous research that related with the project will be in chapter two. The review from the previous study that can be related with this project including the method that have been used will be stated in this chapter. Also, any related information about this project will be included in this chapter.

Chapter three will be consist of methodology that involve in the project. In this chapter, each step in achieving the objective and the way to obtain the result required will be elaborated. Then, all results for this project will be stated and discuss in chapter four. The data will be analyzed and conclude in this chapter. The last chapter which is chapter five, there will be a conclusion for the whole project and recommendation for this study in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Most machine that have been invented either manual or automatic operation, was based on the same concept which is open-loop where it will receive a signal from the main component to be functioning. There is no feedback sensor that measured the actual output response to be compared with the desired input signal. The condition of open-loop system is shown in Figure 2. 1:

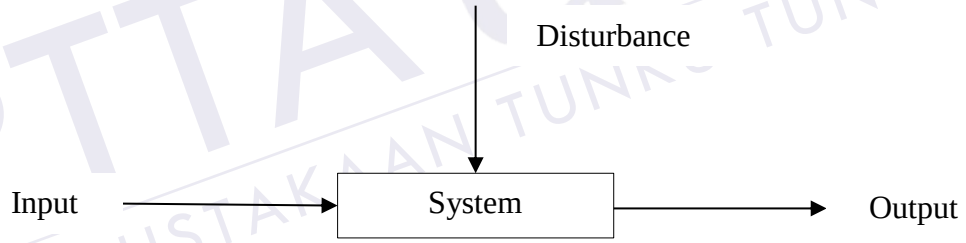

Figure 2.1: The condition of the open-loop system operation.

The current system also is an open loop system as there is no feedback mechanism to bring the output to the input to be compared with the desired input. The main component of the toothbrush simulator was the microcontroller, Arduino which the whole programming of the system was uploaded into it. In this case there was an actuator that produce the output of the system. There is no controller in the current toothbrush simulator system. Hence, the toothbrush holder motion was not constant where it will become slower and stop eventually when there is a force exerted on it.

Constant brushing motion was important because 17,800 strokes need to be achieved to do adequate test dental research. Operational process of the toothbrush simulator system can be improved by applying automatic control theory on the system.

REFERENCES

Abdul-Rahman, O., Munetomo, M., & Akama, K. (2011). An Improved Binary-Real Coded Genetic Algorithm for Real Parameter Optimization. *Proceedings of the 2011 3rd World Congress on Nature and Biologically Inspired Computing, NaBIC 2011*, 149–156. https://doi.org/10.1109/NaBIC.2011.6089451

Ali W. W. N. S., Sapoon M. S., Rosdi N. M., Halib N., & Mohamed N (2018). The Two-Dimensional Effects of *Salvadora Persica* Mechanical Brushing on The Surface of Polymethyl Methacrylate Denture Base Material. *Journal of International Dental and Medical Research.*

Almali, N., & Bahir, K. S. (2016). Arduino Based Smart Home Automation System, *2*(2), 1–5.

Andrijić, Ž. U., Bolf, N., & Rolich, T. (2011). Optimizing Configurable Parameters of Model Structure Using Genetic Algorithms. *TEDI -International Interdisciplinary Journal of Young Scientists from the Faculty of Textile Technology TEDI*, *1*(January), 49–54.

Ang, K. H., Chong, G. C. Y., & Li, Y. (2007). PID Control System Analysis , Design , and Technology, *13*(November), 559–576. https://doi.org/10.1371/journal.pone.0200480

Angelova, M., & Pencheva, T. (2011). Tuning Genetic Algorithm Parameters to Improve Convergence Time. *International Journal of Chemical Engineering*, *2011*. https://doi.org/10.1155/2011/646917

Aström, K. J., & Murray, R. M. (2010). *Feedback Systems: An Introduction for Scientists and Engineers*. Princeton university press. https://doi.org/10.3201/eid2109.141665

Baqais, A. (2016). Genetic Algorithm for Function Approximation : An Experimental Investigation. *International Journal of Artificial Intelligence and Applications (IJAIA)*, *7*(3), 1–9. https://doi.org/10.5121/ijaia.2016.7301

Barhate, N. K., & Ingle, K. S. (2015). Farm Monitoring Mobile Robot Speed Controlled of DC Motor Driver System Using PID Controller ., *4*(1), 9950–9953.

Barrero, D. F., Gonźalez-Pardo, A., Camacho, D., & R-Moreno, M. D. (2010). Distributed Parameter Tuning for Genetic Algorithms. *Computer Science and Information Systems*, *7*(3), 661–677. https://doi.org/10.2298/CSIS100118013B

Bature, A. A., Buyamin, S., Ahmad, M. N., Muhammad, M., & Muhammad, A. A. (2015). Identification and Model Predictive Position Control of Two Wheeled Inverted Pendulum Mobile Robot. *Jurnal Teknologi*, *73*(6), 153–156.

Bhuvaneswari, N. S., Praveena, R., & Divya, R. (2012). System Identification for Interacting and Non-Interacting Tank Systems Using Genetic Algorithm, 385–395.

Bista, D. (2016). Understanding and Design of an Arduino-Based PID Controller Understanding and Design of an Arduino- Based PID Controller.

Biswas, S. P., Hosain, M. K., & Rahman, M. W. (2018). Real-Time Arduino Based Simulator Enabled Hardware-in-the-Loop Electric DC Machine Drive System. *5th IEEE Region 10 Humanitarian Technology Conference 2017, R10-HTC 2017*, *2018–January*, 823–826. https://doi.org/10.1109/R10-HTC.2017.8289082

Burgos, M., Getto, D., & Berne, P. (2005). System Identification By Experiemntal Data Processing, Application to Turbulent Transport of A Tracer in Pipe Flow. *International Nuclear Atlantic Conference-INAC 2005*.

Chang, W. (2007). Nonlinear System Identification and Control Using a Real-Coded Genetic Algorithm (Vol. 31, pp. 541–550). https://doi.org/10.1016/j.apm.2005.11.024.

Currey. Arduino with HC-05 Bluetooth Module in Slave Mode. October 27, 2014. Accessed 1 November 2018 from http://www.martyncurrey.com/arduino-with hc-05-bluetooth-module-in-slave-mode/ .

Curtis, A. R. (1991). An Application of Genetic Algorithms to Active Vibration Control. *Journal of Intelligent Material Systems and Structures*, *2*(4), 472-481.

Daudi, J. (2015). An Overview of Application of Artificial Immune System in Swarm Robotic Systems. *Advances in Robotics & Automation*, *4*(1), 1–6. https://doi.org/10.4172/2168-9695.1000127

de Freitas Pontes, K. M., de Holanda, J. C., Fonteles, C. S. R., de Barros Pontes, C., da Silva, C. H. L., & Paranhos, H. D. F. O. (2016). Effect of Toothbrushes and Denture Brushes on Heat-Polymerized Acrylic Resins. *Gen Dent*, *64*(1), 49-53.

Dorigo M., Birattari M. & Stutzle T. (2006). Ant Colony Optimization: Artificial Ants as a Computational Intelligence Technique. *IEEE Computational Intelligence Magazine*, 28–39.

Dubey, S., & Srivastava, K. (2013). A PID Controlled Real Time Analysis of DC Motor. *International Journal of Innovative Research in Computer and Communication Engineering*, *1*(8), 1965–1973.

ElAli, T. S. (2016). *Discrete systems and digital signal processing with MATLAB*. *CRC press.*

Eshkabilov, S., & Madirimov, E. (2013). Mathematical Modeling and System Identification Aspects of Heat Flow Process Inside a Closed Box, 1–13.

Fruk, M., Vujisić, G., & Špoljarić, T. (2013). Parameter Identification of Transfer Functions Using MATLAB. In *Information & Communication Technology Electronics & Microelectronics (MIPRO), 2013 36th International Convention on* (pp. 571–576). IEEE.

Gockel, T., Salb, T., Weyrich, T., Burgert, O., & Dillmann, R. (2001). Interactive Simulation of Teeth Cleaning. *In International Congress Series*, *1230*, 682–688. Retrieved from https://www.sciencedirect.com/science/article/pii/S053151310100111X

Hassan, M. M., Aly, A. A., & Rashwan, A. F. (2007). Different Identification Methods with Application to a DC Motor 1 . 2 System Identification Procedures, *35*(6), 1481–1493.

Huang, Y., Gao, L., Yi, Z., Tai, K., Kalita, P., Prapainainar, P., & Garg, A. (2017). An Application of Evolutionary System Identification Algorithm in Modelling of Energy Production System. *Measurement: Journal of the International Measurement Confederation*, *114*(August 2017), 122–131. https://doi.org/10.1016/j.measurement.2017.09.009

Hui, Z., Qin, L. L., & Gang, W. (2017). Modeling and Simulation of Greenhouse Temperature Hybrid System Based on ARMAX Model. *Chinese Control Conference, CCC*, 2237–2241. https://doi.org/10.23919/ChiCC.2017.8027690

Hussin, M. S., Azuwir, M. N., & Zaiazmin, Y. N. (2011). Modeling and Validation of Brushless DC Motor. *2011 4th International Conference on Modeling, Simulation and Applied Optimization, ICMSAO 2011*, 0–3. https://doi.org/10.1109/ICMSAO.2011.5775620

Jahaya, J., Nawawi, S. W., & Ibrahim, Z. (2011). Multi Input Single Output Closed Loop Identification of Two Wheel Inverted Pendulum Mobile Robot. *In Research and Development (SCOReD), 2011 IEEE Student Conference on IEEE.*, 138–143. https://doi.org/10.1109/SCOReD.2011.6148723

Joshi, B., Shrestha, R., & Chaudhary, R. (2014). Modeling , Simulation and Implementation of Brushed DC Motor Speed Control Using Optical Incremental Encoder Feedback DC Motor Model Simulink Modeling , Simulation and Parameter estimation. *Proceeding of IOE Graduate Conference*, (November), 497–505.

Julai, S., Tokhi, M. O., & Salleh, S. M. (2009). Active Vibration Control of a Flexible Plate Structure Using Ant System Algorithm. *EMS 2009 - UKSim 3rd European Modelling Symposium on Computer Modelling and Simulation*, (1), 37–42. https://doi.org/10.1109/EMS.2009.63

Katsambe, C. T., Luckose, V., & Shahabuddin, N. S. (2017). Effect of Pulse Width Modulation on DC Motor Speed. *International Journal of Students' Research in Technology & Management*, *5*(2), 42–45.

Khaled, A. ., Paul, S. K., Ripon, K. C., & Ayuby, M. S. (2011). Selection of Suppliers Through Different Multi-Criteria Decision Making Techniques. *Global Journal of Management and Business Research*, *11*(4).

Khandalkar, B., Amit Lamba, A. P., & Vipin Bhure, A. P. (2015). Design and Analysis of Digital PID Controller. *International Research Journal of Engineering and Technology*, 2395–56.

Kiruthika, A., Rajan, A. A., & Rajalakshmi, P. (2013). Mathematical Modelling and Speed Control of a Sensored Brushless DC Motor Using Intelligent Controller. *2013 IEEE International Conference on Emerging Trends in Computing, Communication and Nanotechnology, ICE-CCN 2013*, (Iceccn), 211–216. https://doi.org/10.1109/ICE-CCN.2013.6528495

Kristinsson, K., & Dumont, G. A. (1992). System Identification and Control Using Genetic Algorithms. *IEEE Transactions on Systems, Man, and Cybernetics*, *22*(5), 1033–1046.

Kulkarni, V. V., Kulkarni, V. A., & Talele, R. (2017). PID Controller Based DC Motor Speed Control. *International Journal on Recent and Innovation Trends in Computing and Communication*, *5*(9), 35–38.

Lai, W. K., Rahmat, M. F., & Wahab, N. A. (2012). Modeling and Controller Design of Pneumatic Actuator System with Control Valve. *International Journal on Smart Sensing and Intelligent Systems*, *5*(3), 624–644.

Lee, Y. H., Park, S. K., & Chang, D. E. (2006). Parameter Estimation Using The Genetic Algorithm and its Impact on Quantitative Precipitation Forecast. *Annales Geophysicae*, *24*(12), 3185–3189. https://doi.org/10.5194/angeo-24-3185-2006

Lin, M. H., Tsai, J. F., & Lee, L. Y. (2013). Ant Colony Optimization for Social Utility Maximization in a Multiuser Communication System. *Mathematical Problems in Engineering*, *2013*. https://doi.org/10.1155/2013/798631

Ljung, L. (1987). *Ljung L System Identification Theory for User.pdf*. *PTR Prentice Hall Upper Saddle River NJ* (Vol. 25). https://doi.org/10.1016/0005-1098(89)90019-8

Marco, D., Mauro, B., & Thomas, S. (2006). Ant Colony Optimization. *IEE Computational Intelligence Magazine*, *1*(4), 28–39. https://doi.org/10.1109/MCI.2006.329691

McCall, J. (2005). Genetic Algorithms for Modelling and Optimisation. *Journal of Computational and Applied Mathematics*, *184*(1), 205–222. https://doi.org/10.1016/j.cam.2004.07.034

Mehedi, S. T. (2015). DC Motor Armature Speed Control with PID Controller (December 2014). *IEE Journal of Control Engineering*, (May), 1–8. https://doi.org/10.13140/RG.2.1.4492.1764

Mohamed, N. M. A., Abdalaziz, A. A. A., Ahmed, A. A., & Ahmed, A. A. A. (2017). Implementation of a PID Control System on Microcontroller (DC Motor Case Study). *Proceedings - 2017 International Conference on Communication, Control, Computing and Electronics Engineering, ICCCCEE 2017*, (1), 2–6. https://doi.org/10.1109/ICCCCEE.2017.7866088

Mohammed, J. A. (2013). Pulse Width Modulation for DC Motor Control Based on LM324. *Eng. & Tech. Journal*, *31*(10), 1882–1896.

Mon, Y. (2015). The Bluetooth Based LED Control For Arduino Test Platform By Using Mobile App. *International Journal of Scientific & Technology Research*, *4*(6), 330–332.

Mubark, A., Osman, M., & Hussein, E. M. (2017). Home Automation System via Android With Security Camera, *45*(1), 100–105.

Muthuvignesh, M., Karthick, M., Nallakaruppan, M., Jagadeshkumar, S., & Sathishkumar, R. (2017). Temperature Control of Steam Using Microcontroller Arduino MEGA 2560, 3504–3511. https://doi.org/10.15680/IJIRSET.2017.0603091

Nagaraja, G. (1991). Applications of A.I. in Control Systems. *ACE '90. Proceedings of [XVI Annual Convention and Exhibition of the IEEE In India]*, 111–114.

Nath, A. S. N., Aravind Kumar, R., & Malik, T. (2013). Implementation of PID Control to Reduce Wobbling in a Line Following Robot. *International Journal of Research in Engineering and Technology*, *2*(10), 531–535.

Oladejo, K. A., Adetan, D. A., Adewale, M. D., & Malomo, B. O. (2016). Model for Design Concept Evaluation Using Decision-Matrix Logic, *7*(2), 6–14.

Osman, K., Mohd Faudzi, A. A., Rahmat, M. F., & Suzumori, K. (2014). System Identification and Embedded Controller Design for Pneumatic Actuator with Stiffness Characteristic. *Mathematical Problems in Engineering*, *2014*. https://doi.org/10.1155/2014/271741

Othman, K., & Kamal, M. (2009). System Identification of Discrete Model for DC Motor Positioning. *Proceedings of the 8th …*, 212–216. Retrieved from http://dl.acm.org/citation.cfm?id=1736320

Patil, A., & More, S. (2014). Mathematical Modeling of Physical System. *IOSR Journal of Electrical and Electronics Engineering*, *9*(3), 57–64.

Rabbani, M. J., Hussain, K., Khan, A. U. R., & Ali, A. (2013b). Model Identification and Validation for a Heating System Using Matlab System Identification Toolbox. *IOP Conference Series: Materials Science and Engineering*, *51*(1). https://doi.org/10.1088/1757-899X/51/1/012022

Salleh, S. M., & Tokhi, M. O. (2009). Active Vibration Control of a Flexible Plate Using Real Coded Genetic Algorithm. *IFAC Proceedings Volumes*, *42*(19), 343-348.

Sethuramalingam, T. K., & Karthighairasan, M. (2012). Automatic Gas Valve Control System Using Arduino Hardware. *Bonfring International Journal of Power Systems and Integrated Circuits*, *2*(3), 18–21. https://doi.org/10.9756/BIJPSIC.10001

Shahraki, M., Sh, M. A., & Mousavinia, A. (2017). Two Wheel Self-Balanced Mobile Robot. *Electrical Engineering (ICEE), 2017 Iranian Conference on*, 883–888.

Singh, A. P., Narayan, U., & Verma, A. (2013). Speed Control of DC Motor Using PID Controller Based on Matlab. *Innovative Systems Design and Engineering*, *4*(6), 22–28. Retrieved from http://www.iiste.org/Journals/index.php/ISDE/article/view/6018

Sudhan, R. H., Kumar, M. G., Prakash, A. U., Devi, S. A. R., & P., S. (2015). Arduino ATmega-328 Microcontroller. *Ijireeice*, *3*(4), 27–29. https://doi.org/10.17148/IJIREEICE.2015.3406

Takanashi, H., & Adachi, S. (2006). Development of a GUI for a System Identification Device Using Matlab. *IFAC Proceedings Volumes*, *39*(1), 925–930. https://doi.org/10.3182/20060329-3-AU-2901.00147

Tang, W., Liu, Z., & Wang, Q. (2017). DC Motor Speed Control Based on System Identification and PID Auto Tuning, (61403422), 6420–6423.

Tavakolpour-Saleh, A. R., Nasib, S. A. R., Sepasyan, A., & Hashemi, S. M. (2015). Parametric and Nonparametric System Identification of an Experimental Turbojet Engine. *Aerospace Science and Technology*, *43*, 21–29. https://doi.org/10.1016/j.ast.2015.02.013

Theopaga, A. K., Rizal, A., & Susanto, E. (2014). Design and Implementation of PID Control Based Baby Incubator. *Journal of Theoretical and Applied Information Technology*, *70*(1), 19–24.

Wang, Q. J. (1997). Using Genetic Algorithms to Optimise Model Parameters. *Environmental Modelling & Software*, *12*(1), 27–34. https://doi.org/10.1016/S1364-8152(96)00030-8

Wang, Z., & Bovik, A. C. (2009). MSE : Love It or Leave It ? *IEEE Signal Processing Magazine*, (January), 98–117. https://doi.org/10.1109/MSP.2008.930649

Wati, D. A. R., & Hidayat, R. (2013). Genetic Algorithm-Based PID Parameters Optimization for Air Heater Temperature Control. *Proceedings of 2013 International Conference on Robotics, Biomimetics, Intelligent Computational Systems, ROBIONETICS 2013*, (1), 30–34. https://doi.org/10.1109/ROBIONETICS.2013.6743573

Whorton, M. S. (2004). Closed Loop System Identification with Genetic Algorithms. *In AIAA Guidance, Navigation, and Control Conference and Exhibit*, 4887.

Zhang, J. Z. J., Wang, N. W. N., & Wang, S. W. S. (2004). A Developed Method of Tuning PID Controllers with Fuzzy Rules for Integrating Processes. *Proceedings of the 2004 American Control Conference*, *2*, 1109–1114.